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# An Integrated Approach to Reduced Total Ownership Costs of Aircraft (RTOC)

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## Summary

The Reduced Total Cost of Ownership (RTOC) Study was a unique, “out-of-the-box”, integrated Science & Technology (New Processes & Techniques) approach to obtaining more affordable aircraft weapon systems and modernizing these systems for future combat scenarios. The RTOC Study stands in contrast to the individual “bits & pieces” technology transition plans seen in the past. Individual plans can result in costly programs that are hard to justify and are easily attacked when evaluating fiscal parameters. An integrated Reduced Total Ownership Cost (RTOC) approach, with substantiation data provided by the proposed follow-on effort, would be easily justified by these same fiscal parameters using this new cost database.

## Background

Affordability has become the number one issue to today’s military planners. This affordability thrust, however, is slightly different than those of the past. This time this thrust is being driven out of “need”. As stated in Figure 1, today forty-one percent (41%) of the United States Air Force (USAF) total inventory is over 24 years old. By the year 2005, seventy-five percent (75%) of the total inventory will be over 20 years old. The B-52 and KC-135 will be approaching 60 and 80 years of duty, respectively, at their currently planned retirement dates. The cost of sustaining this aging inventory as a viable military force continues to increase for several reasons: economic obsolescence, high operations tempo, aging of aircraft subsystems, new operational techniques, and a reduction in experience level of the maintainer just to mention a few. While solutions are available to maintain these weapon systems as viable 21<sup>st</sup> Century vehicles, in most cases, the non-recurring cost is prohibitive. The funding for these upgrades must compete with basic fleet maintenance and other modernization activities.

In those cases where technology insertion has been implemented, it usually has been by individual subsystem upgrades, a “bits & pieces” approach. While such an approach can meet key operational needs and reduce subsystem maintenance, the stand-alone upgrade bears the entire development and implementation costs by itself. Additionally, stand-alone upgrades, while improving Reliability & Maintainability (R&M) of individual system, may not impact the total weapon system R&M performance. If the integrated weapon system R&M performance is not improved, the weapon system will experience a lower operational readiness and potentially a reduced combat effectiveness. This could be labeled as an

“unbalanced” O&S design. The benefits of technology insertion can be lost if the cost of implementation is considered “too high for the benefits achieved”. Arriving at a realistic “business case” for implementation of a given technology is as important as developing the technology itself. In the case of many technologies, however, it may be that traditional estimating models do not adequately account for the technical and/or process benefits afforded or the current database is inadequate to predict the cost and/or the savings. The “bits & pieces” upgrade philosophy, coupled with tightly constrained budgets, have precluded the ability to create the data required for establishing an integrated cost model for new technology.

### **Study Objectives/ Requirements**

The RTOC Study had the following major objectives. The first major objective was to validate that technology can reduce the life cycle cost of an aircraft by 40 to 60 percent. The baseline aircraft for this study was an existing aircraft that has an extensive cost database and weight and volume trade space for meaningful R&M studies. The study’s focus was on acquisition, RDT&E, and O&S cost savings. The current Air National Guard operations tempo and basing was used to formulate cost comparisons.

The second objective focused on critical aircraft design and assembly processes with the idea of “Revolutionizing the Aircraft Industry”. Critical design and assembly processes necessary to achieve the full benefit of the new technologies must be identified and/or defined. These processes support the elimination of Programmed Depot Maintenance (PDM), provide efficient growth in aircraft systems, utilize the new cost implementation models, reduce the cost sensitivity to production rates/line breaks, and achieve sustainable high levels of R&M over the life cycle of the weapon system

Two key requirements for the RTOC Study were (1) the primary mission would be air-to-air, and (2) the current mission performance could not be reduced. The configuration defined during the study met these criteria, but possessed a robust air-to-ground potential and a significant mission growth capability. This configuration also allows for an easy conversion to a two-seat variant for future growth and flexibility to accommodate future technology demonstration tasks.

Figures 2&3 show the problem in historical terms. We are all used to the cost estimating relationships being expressed as log-log curves as shown in figure 2. The problem with using these curves is that we have lost not only the historical data on them but also we do not know how these curves have been impacted by the need for obtaining the utmost in performance at any cost. This chart graphically shows the problem. We are very comfortable in estimating cost between the top two lines. But technology demonstration programs have shown that we can get down to the lower line. The problem is getting the cost community to accept this as the current state of the art. The cost community includes everyone in that process from the initial engineering estimate to the final cost that we see in the formal proposal.

The second area where cost estimating relationships are not able to capture the impact of technology is the learning curve as shown in figure 3. This chart is another example of the cost-estimating dilemma. This is a learning curve. It is used to adjust the historical data over the projected buy and the efficiency introduced when you build the same thing over and over again. Where you draw this curve makes a big impact on the cost of you first articles and total program costs. Today’s technologies are driving this curve to a nearly straight horizontal line. This says that costs could be independent of quantity buys. That is the first article costs as much to build as the last article. This is a significant impact on program costs and says that in the extreme you could be independent of production line break, as there is little learning curve to retain. With virtual reality, we are now able to build and assemble a large structure many times in the computer and with the latest technology we are now close to making this curve essentially a horizontal line.

### **Technology Maturity**

One important factor to be considered in a study of this kind is to ensure that any proposed technology has an appropriate maturity in order to manage risk and avoid cost overruns. One tool for assessing this is known as Technology Readiness Level (TRL), see Figure 4. The TRL goes from a value of 1 for a basic idea through a defined range up to a value of 9 for something in 'operational use'. These values must be qualified in more detail depending on various factors. If the technology, or component, is in operational use on a different military aircraft system then there is little question about the TRL. Only the integration issues, or changes required, need to be analyzed for a credible assessment to be made. On the other hand,

Commercial Off The Shelf (COTS) equipment is popularly considered to be a potential cost saver for military applications. Something that is in routine commercial use may still need qualifying for different environmental factors. It is also possible that it can be decided that there is no significant difference and a TRL of 8 can be assumed for application. One factor that will have a strong influence on the analysis is whether the technology under consideration is considered flight safety critical, or mission critical, or less critical. Obviously, flight safety critical items will receive the closest scrutiny. We can consider the flight control system to be in this category and will be discussed as an example.

The F-15 is a good illustration of the process because it has a mechanical flight control system that is a significant maintenance item. New high-performance fighters are designed with digital control systems for reasons of cost and performance, and such a change must be a consideration for the study. There is no COTS possibility, the military are ahead of all commercial applications in this area because of the flight envelope and maneuverability requirements. Replacing the mechanical system with a new design would be a significant development effort. In order to avoid the cost of developing a new FCS, we must look at other possibilities. In terms of a system in operational use (to maximize the TRL), we might consider the F/A-18E/F. While there would be many similarities, the control laws for carrier landing would certainly need to be modified for USAF operation. Next we can consider a control system that has flown in research programs. Both the STOL & Maneuver Technology Demonstration (S/MTD) program and the Advanced Control Technology for Integrated Vehicles (ACTIVE) program have used an F-15 to conduct thrust vectoring research programs. The S/MTD flight control system was designed with a new digital control system with no dissimilar backup and first flew in 1988. A primary objective of the program was to integrate thrust reversing and pitch vectoring into an integrated Flight/Propulsion Control system. The control system also included a reversionary mode that did not use any of the propulsive control components as a reference for the other research control modes. Referred to as the CONVENTIONAL mode, it enabled the aircraft to fly and feel to the pilot like a normal F-15 but with subtle improvements. After the S/MTD program finished, the same testbed was modified to incorporate pitch/yaw vectoring nozzles for the ACTIVE program. The same CONVENTIONAL mode was retained and flight testing has continued to this date. This hardware could be considered to be at a TRL of 8, i.e. flight qualified through test and demonstration. The control laws and software of the mode might be considered at a TRL of 7, although it has been operating successfully for twelve years it has not been cleared for unrestricted flight throughout the F-15 envelope.

The preceding discussion is intended as an example of a process that can be used to help in ranking competing technologies or alternatives. It is intended to reduce some of the subjectivity in assessing the readiness of technologies, both hardware and software, for application in a production system.

### **Study Results**

The study duration was nine months and the deliverables included the definition of:

- (1) A reference aircraft configuration that would reduce Total Ownership Cost,
- (2) The identification of new, robust design and assembly procedures that when implemented would incorporate new technologies and processes.
- (3) Identification of new maintenance and supply concepts that reduce the Life Cycle Costs.

Because the study was only nine months long, we concentrated on the life cycle elements highlighted in figure 5. This is significant in that later on in the paper you will see substantial savings and you must remember that we not only did not address all aspects of life cycle costs but also we did not study everything to the same depth. So the results we show at the end of this paper are very conservative.

After establishing and zero basing the baseline production configuration, the air-to-air superiority production baseline was established. Sixty-three (63) trade studies were defined that offered the potential to reduce the total ownership cost and/or to provide essential 21<sup>st</sup> Century aircraft system capability. The 63 trade studies and numerous S&T program opportunities resulted from numerous, joint brainstorming sessions with numerous technology experts. Following an iterative process of analyses and review, the findings of 47 trade studies were approved for the study aircraft. Another 6 were selected as options for future consideration (Fig 6), and the remaining 11 were not approved. The production baseline modified by the 47 approved trade studies is the final configuration for the study. This configuration was used for O&S and acquisition cost comparisons with the baseline configuration.

We will now show a few examples of the results of the trade studies.

### **Design / Manufacturing Processes**

As part of the study, a new, robust aircraft design and assembly process provide a flexible, most cost effective process for building, modifying, supporting, and maintaining the study aircraft over its 20 year life cycle. (Fig 7)

The robust, flexible, design and assembly process to be utilized for the study aircraft combines three-dimensional computer aided engineering/re-engineering of the current design coupled with selected applications of Design for Manufacture and Assembly (DFMA). DFMA adds to the 3D computer aided design tools, the introduction of more durable materials, improved designs, automated manufacturing processes, and affordable tooling. During the Phase I Study in-depth technical and cost analyses of the application of these modern methodologies to the current production baseline design were accomplished. The results of these analyses determined that 3D computer re-engineering would be applied to all areas of the design. DFMA techniques would be used for a redesign of the forward fuselage, the wings, and selectively applied in the empennage and center fuselage areas of the fighter. The most direct affect of these new processes is a large reduction in fabrication and assembly hours and the corresponding cost savings.

A major benefit of the computer-based design is the flexibility to manufacture major aircraft structure at the most cost effective location, and then be able to mate the structural sections from the various locations with minimum design refinements. Thus, 3D re-engineering combines improved design and assembly processes with the lowest cost manufacturer.

In addition to the above benefits, several avionics and subsystem upgrades can be directly incorporated into the 3D re-engineering and DFMA design processes. This inclusion of the avionics/subsystem upgrades can significantly reduce the aircraft (non-recurring) costs of implementing lower cost avionics/subsystem enhancements. The computer basis of the design will continue to make future growth driven upgrades more efficient, and have a positive impact on maintenance training and line maintainer efficiency. It also couples with the use of electronic technical orders.

An example of the benefit of this technology on parts count and assembly is shown on figures 8 & 9 but the problem of incorporating this technology in cost estimating is also shown. When the cost estimating was accomplished using historical methods for 115 units, the estimated cost of these assemblies were predicted to increase even though there was approximately a 50% parts count reduction. This is because the models are weight based and we allowed the weight to increase if it simplified a fabrication or build problem. The delta's in the cost estimates highlight the uncertainty in the estimating techniques even for simple structure.

### **Effect on Maintainability**

A significant part of achieving RTOC savings is improved Reliability and Maintainability (Fig 10). The study aircraft configuration provides significant improvement in R&M versus the baseline. These improvements are across all major subsystems within the aircraft. This is very significant. Not only does this reduce the overall unscheduled maintenance man-hours of the aircraft by approximately 70%, but by balancing the improvement across all areas ensures an overall system impact. The steeper slope maintenance man-hours for the different subsystems indicates the criticality of certain key "bad actors" to overall weapon system performance. If not addressed for any reason, a single subsystem can drive the total aircraft maintenance requirements. Figure 11 shows what the maintainer of the near future could be. With electronic maintenance instructions interwoven with 3 dimensional solid models, the maintainer has not only everything he needs to accomplish the required maintenance action, but also to train in virtual reality while the aircraft is returning to base with the known maintenance squawks.

Coupled with the improved R&M, the aircraft configuration possesses features that will provide significant assistance to the aircraft maintainer. The Organizational to Original Equipment Manufacturer (O-to-OEM) maintenance concept can greatly simplify flight maintenance by providing a "remove and replace" approach. The O-to-OEM approach is facilitated by highly reliable equipment with improved diagnostics. The Vehicle Management System is a key example of the improved diagnostics available within the 21<sup>st</sup> Century configuration. Finally, the use of new generation of electronic technical orders (Interactive

Electronic Technical Manuals - IETMs) will provide more available, more explicit support of the flight line maintainer both at home and when deployed. The improved R&M, a balanced O&S design, elimination of PDM, and next generation aids for the maintainer combine to have a significant impact on Total Cost of Ownership. This combination also reduces the impact of lower maintainer experience levels currently experienced in the fleet.

### **Deployment Footprint**

We did a small study on deployment footprint and got significant results that will cause us to look at this area in the next phase. By adding an APU to the configuration, we were able to reduce the deployment requirements for airlift. Figure 12 shows the reduction in airlift requirements by adding an APU to the airplane so it could be maintained away from main operating bases with a reduction in ground support equipment

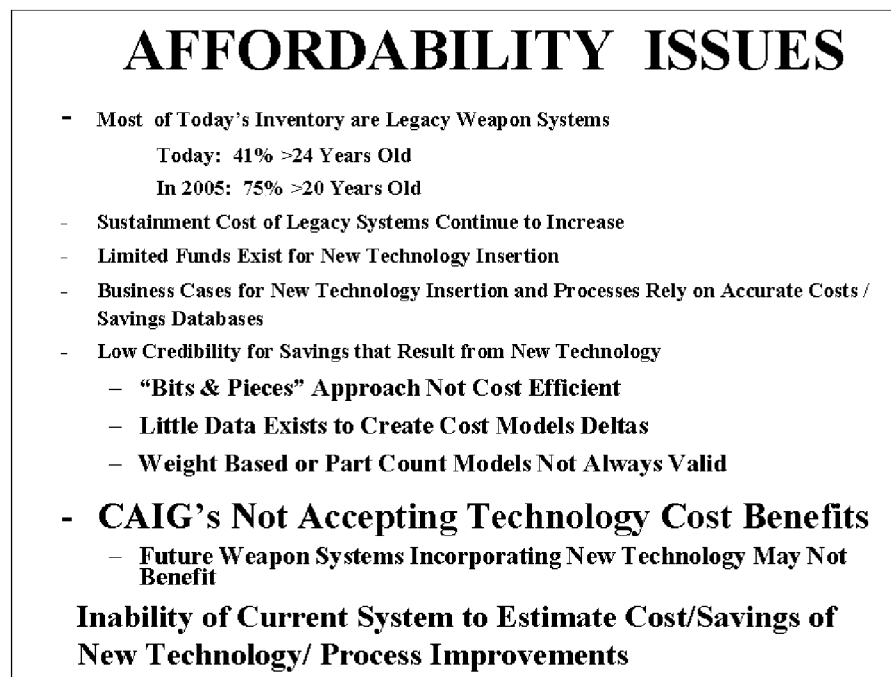
### **Final Results**

From the study, we were able to potentially reduce the acquisition costs by 40-60%; the O&S costs by 40-70%; and direct personnel support by 25-55%. Remember that with these results, we did not address the total Life Cycle Costs so there are more opportunities for cost reduction than what is presented in this paper. Along the way, we started talking about an aircraft that has a scheduled inspection cycle of 100,000 miles or 5 years. Although starting as a joke, it did start people thinking “out of the box” and we have new ideas to explore for future reductions in cost of ownership.

The study showed the necessity of obtaining new certified cost metrics so that everyone understands the impact of technology on historical cost estimating relationships. Also we think this process will revolutionize the aircraft industry and the Air Forces of the world.

### **Summary**

The RTOC configuration achieved all the objectives of the study, and met a large majority of the USAF defined future requirements. The integration of new technology, flexible acquisition systems, and advance processes can reduce the cost of ownership of all aerospace systems. But these technologies/ processes can only be implemented after the data is gathered so that the business cases can be made to use the technologies.



**Figure 1**

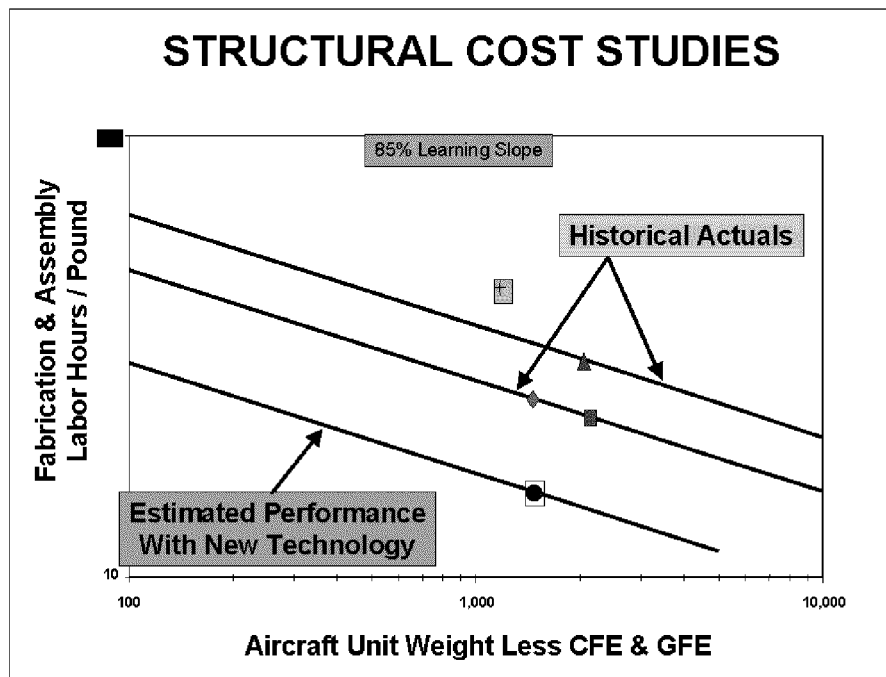


Figure 2

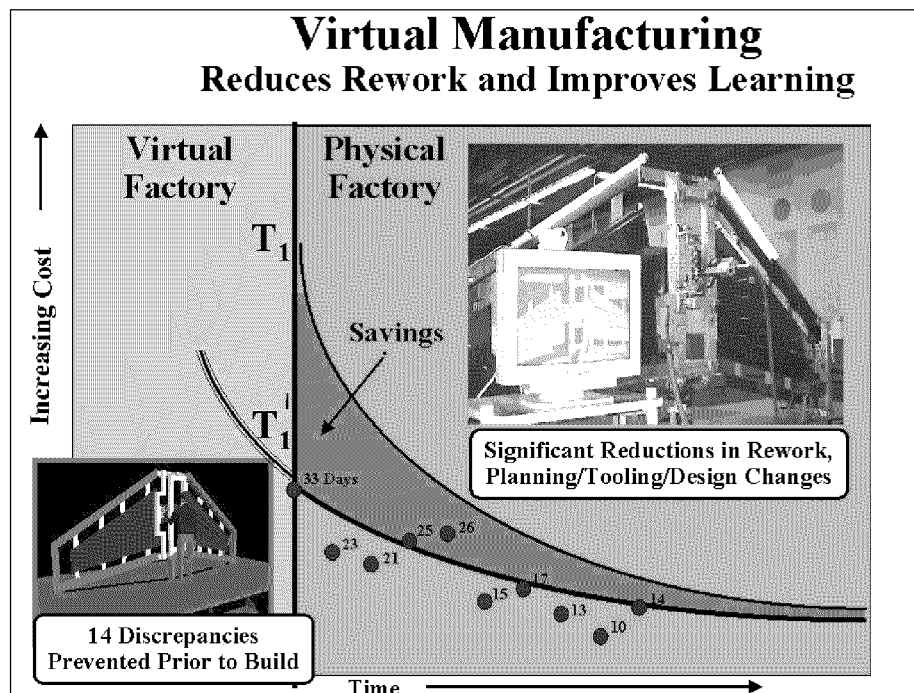


Figure 3

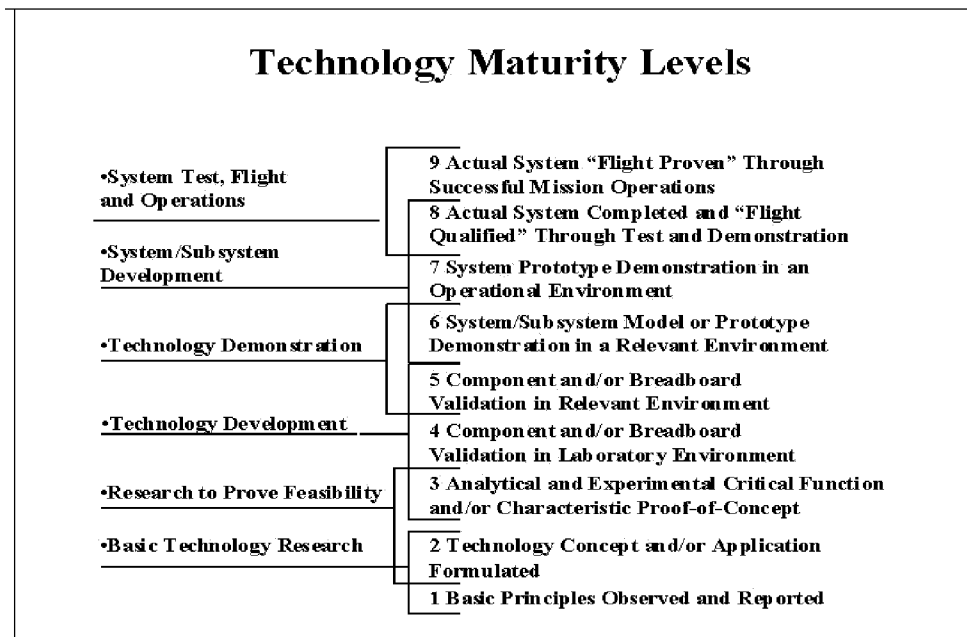


Figure 4

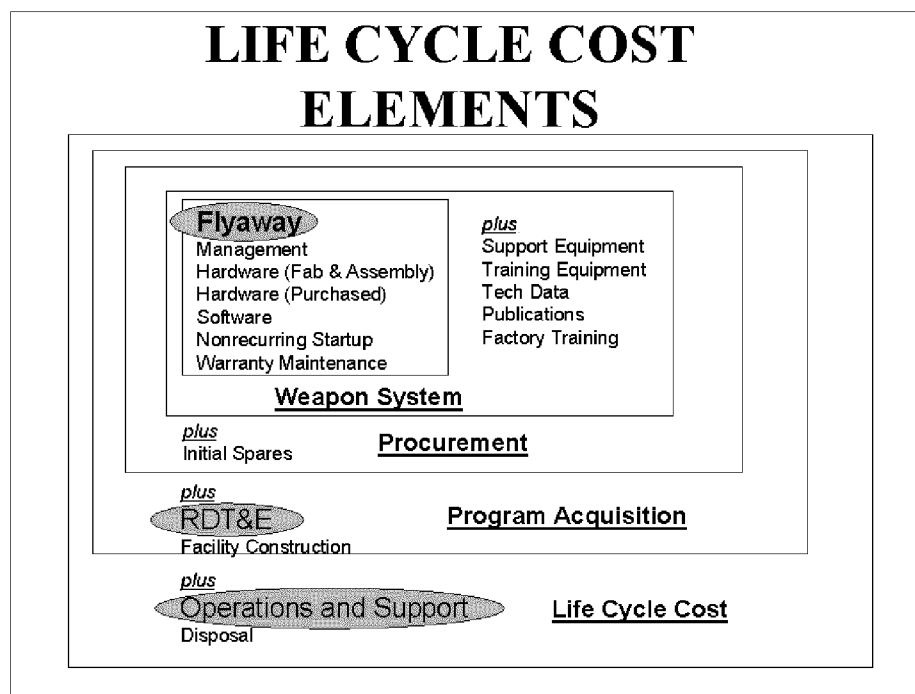


Figure 5



# 21<sup>st</sup> Century RTOC Trade Studies

## AVIONICS MODERNIZATION

- Modern EW System
- Advanced Programmable Armament Control Set
- Joint Helmet Mounted Cueing System
- Improved Communication System
- Advance Display Core Processor
  - Object Oriented Software
- APG-63(V)1 Radar
  - ESA Structural Provisions
- Modern Open System LRU's
- Liquid Crystal Displays
- Night Vision Cockpit
- Fighter Data Link
- High Speed Bus

## ADVANCED WEAPON CAPABILITY

- Multi-Role
- Increased -1760 Capability
- High Off-Bore Sight Missile
- Pn Bomb Rack Option

## NEW PROCESSES / TECHNIQUES

- Lean Certification
- Open System/Commercial Technology
- Lean Maintenance
- End-to-End 3-D Electronic Modeling
- Manufacturing Fabrication / Assembly
- Commercial Business Practices

## REDUCED O&S COST

- Two Level Maintenance
- High Reliability Avionics
- Improved Diagnostics
- Eliminate Structural PDM
- Enables Portable Maintainer
- Reduced Specialty Codes

## SUBSYSTEM IMPROVEMENTS

- Vehicle Management System with:
  - Digital Fly-By-Wire
  - Throttle-By-Wire
  - Remote Interface Units
- Modern Direct Drive Actuators
- Improved Reliability Engines
- Auxiliary Power Unit

## STRUCTURAL ENHANCEMENTS

- New Wing & Vertical Tail
- Grid-Lock Control Surfaces
- Common Engine Bay
- Eliminate Exotic Materials
- Reduced Part Count

Figure 6

## 3D Re-Engineering Process

**"3D RE-ENGINEERING"** Applies Advanced Computer Aided Design Tools to an Existing Design to Improve Part Fit-Up and Tooling Use  
 → Reduces Assembly Labor and Cycle Time

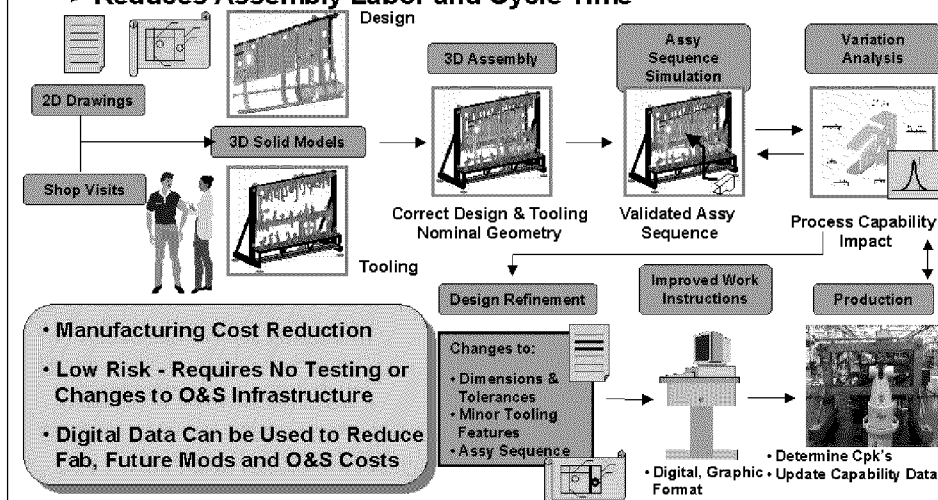


Figure 7

## Preliminary Center Fuselage Re-Design Recurring Cost Benefits

### Baseline Configuration -

- Approximately 2,500 Structural Parts (not including clips/brackets)
- Majority of Parts are Formed Aluminum Sheet and Extrusions
- Weight approximately 5,000 lb
- Simple Fabrication
- Complex Assembly

### Re-Design Configuration -

- Approximately 1,100 Structural Parts (not including clips/brackets)
- Primarily Composite Skins/Ducts and Aluminum HSM Substructure
- Weight approximately 5,400 lb (More Composites, Less Thickness Tailoring)
- Automated Fabrication
- Simpler Assembly

**40-50% Reduction Structural Parts**  
**20-30% Fastener Count Reduction**  
**10-15% Increase In Cost Per Unit**

Figure 8

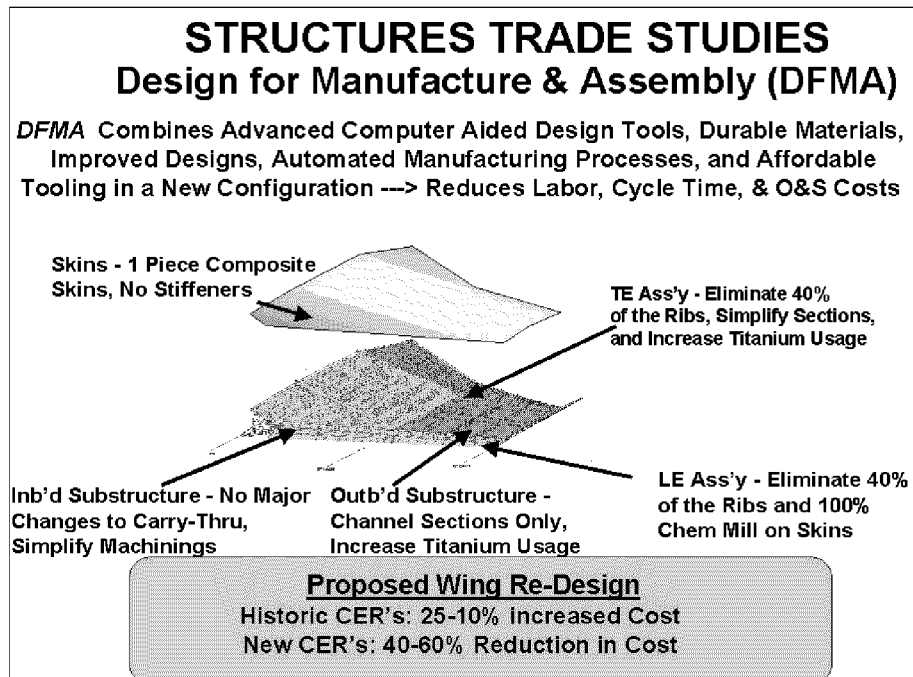


Figure 9

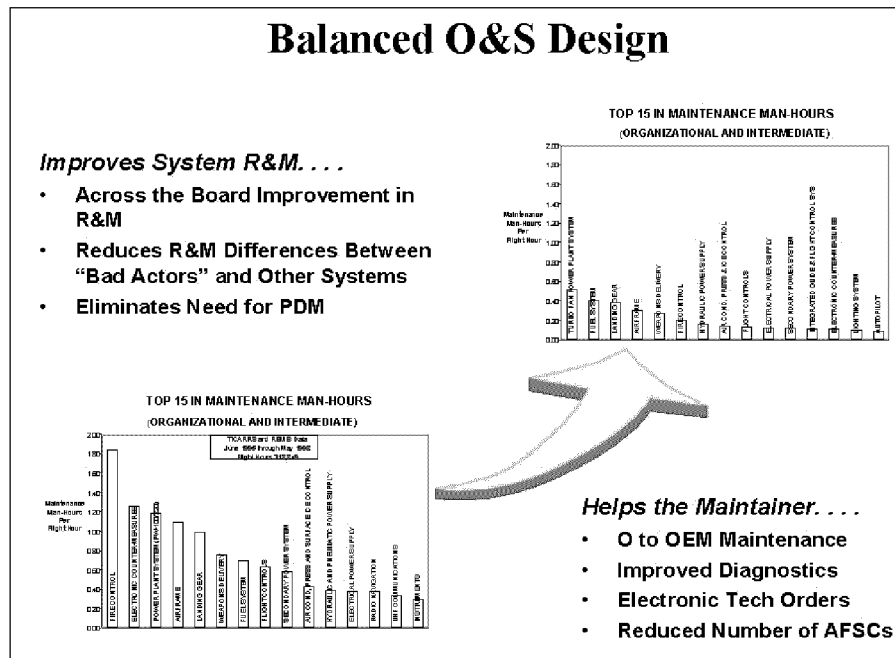


Figure 10

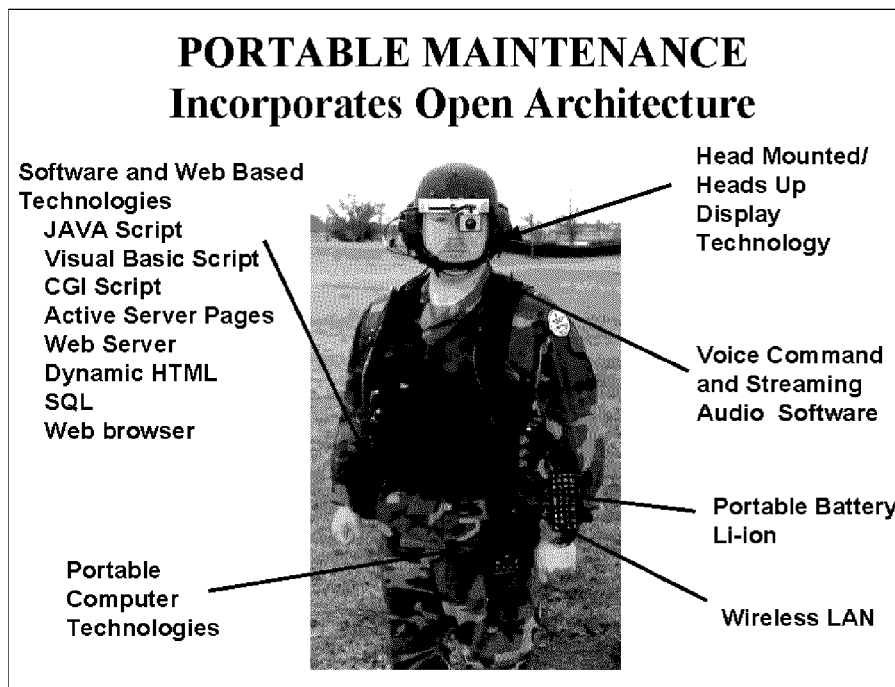
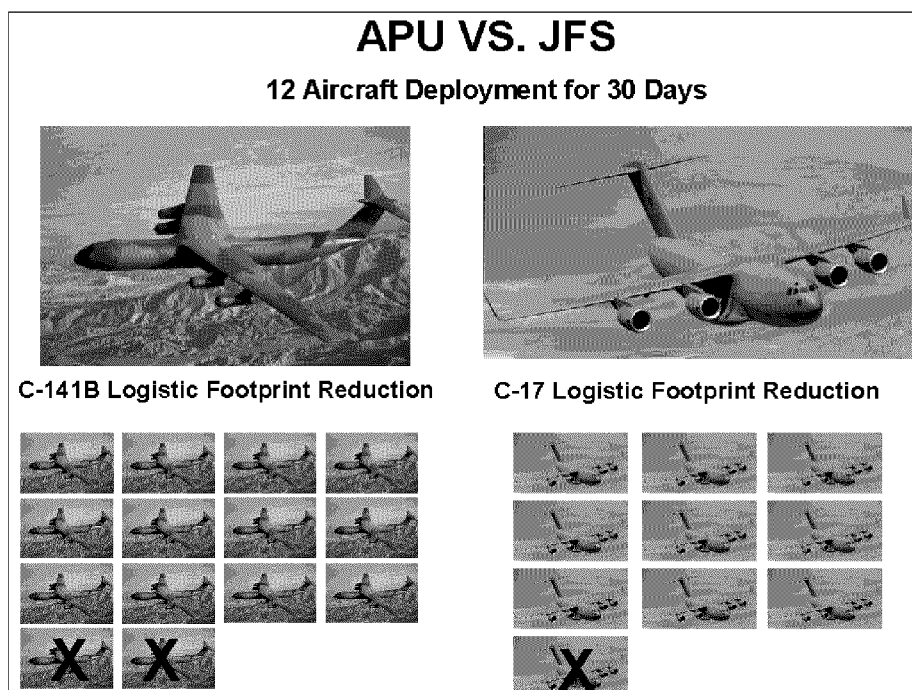


Figure 11



**Figure 12**

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